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A Survey of Bioastronautics 1961–1962 Resources for Research and Development

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Per phone call to Mrs. Lewis, Tech. Reporting Sec., AFSC, Code N, ext. 3160 3 May 62

A SURVEY OF BIOASTRONAUTICS

1961 - 1962

RESOURCES FOR RESEARCH AND DEVELOPMENT

TECHNICAL DOCUMENTARY REPORT NO. HQAFSC-TDR-62-1
February 1962

Assistant for Bioastronautics
Headquarters, Air Force Systems Command
Andrews Air Force Base
Washington 25, D. C.

(Prepared under Contract No. AF 18(600)-1916
by the Cornell Aeronautical Laboratory, Inc.
Buffalo 21, New York)

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A SURVEY OF BIOASTRONAUTICS

1961 - 1962

RESOURCES FOR RESEARCH AND DEVELOPMENT

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FOREWORD

The Cornell Aeronautical Laboratory (CAL) was asked by the Air Force to survey non-government bioastronautics research and development, to the end that our national objectives may best be met and that our scientific community may best be served.

The project that has led to the present report was initiated by Brigadier General Don Flickinger, then Assistant for Bioastronautics to the Commander, Air Force Systems Command, and by Dr. Albert W. Hetherington, Technical Director, Office of the Assistant for Bioastronautics, in February 1961. Plans for the project were formulated in greater detail during the following five months. Full-scale work began in June 1961, under a contract between the Air Force Systems Command and the Cornell Aeronautical Laboratory.

The report has been prepared by a working group composed of engineers, physicists, physicians and psychologists, who are listed as joint authors. Each of these men is actively engaged in research in some area of bioastronautics, and among them combine experience in all areas covered by the report.

The Air Force wishes to thank those 360 organizagions who supplied the data which made the CAL inventory possible, and the many people in government agencies and private organizations who contributed their time, interest, and advice to this project.

ABSTRACT

As space flight progresses, emphasis will shift from current pre-occupation with methods of transportation toward the knowledge to be gained from explorations. Foremost among the questions to be answered by the exploration of space are those concerned with bioastronautics. A research and development program for manned space flight during the next two decades will serve both to establish human productivity in space-based systems and to stimulate the advancement of concepts of military action for exploiting human capabilities.

This report outlines information and ideas which must be considered in the formulation of a long range program aimed at manned exploration and use of outer space.

This report attempts to achieve the following objectives:

1. An accounting of the men, money and skills invested in bioastronautics work by universities, not-for-profit and industrial concerns;

2. An evaluation of the usefulness of their effort to the National program;

3. An appraisal of the research and development now in progress, together with a prognosis of technical accomplishments, and recommendations for research that recognize the magnitudes of the country's scientific skills, facilities, and manpower.

The opinions and conclusions in this report are those of the editor and contributors, and are not to be construed as necessarily reflecting the views of the Air Force Systems Command. This report is approved for publication to provide a broad dissemination of the information it contains.

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A SURVEY OF BIOASTRONAUTICS
1961 - 1962

INTRODUCTION

Bioastronautics is the study of life in space, a science so new that it has scarcely had time to acquire a name; a composite science, broader than exobiology, encompassing every discipline and technology that contributes to the study of life away from the earth. It was inevitable that the consideration of life in its highest form should emerge as a central, impelling theme, so that today we may say that the primary concern of bioastronautics is man in space.

Life in space derives its value from use alone. In the efforts of this nation to put man in space, human productivity is the common denominator, and assessment of this productivity has value to all segments of the military and scientific community. For the Air Force there is but one objective - improving its capability to maintain and safeguard the security and integrity of the nation. The capability of manned satellites for reconnaissance, for surveillance of enemy action, and for early warning are currently under investigation. To the scientific community this assessment of productivity is equally important. Earthbound astronomy is a bit like bird watching from the bottom of a swimming pool. No one can fail to be impressed by the opportunities for dramatic advancement of our understanding of the universe that are present in an inhabited observatory on the moon, free from the obfuscations of earth's atmosphere.

The major objectives of bioastronautics are to insure that the environment in which man lives, the machines he uses and the tasks he performs are consistent with man's own characteristics, capabilities, and preferences. Whether the tasks he performs are of scientific or of military value will have no essential effect on the nature of bioastronautics problems encountered. This survey must, therefore, encompass the full spectrum of problems, not just those peculiar to military operations in space.

Why Man?

Much has been written to justify the effort that will make it possible for man to participate physically in the exploration of space. Many well-informed, well-motivated people decry the use of this country's resources to put a man in space. Many scientists engaged in space research advocate emphasis on instrument-carrying probes. Therefore, why man?

In the first place, research is probing for the unknown. The astronaut is not unlike the young Charles Darwin, who in 1831 accompanied the crew of the "Beagle" on a five-year voyage around the world to explore various coastlines and to increase man's knowledge of geography. Could an instrumented probe disclose the relation of form, color and location of the tortoises and the finches of the Galapagos Islands? Could a television camera from the deck of the "Beagle" elicit the theory of random variation and natural selection? If 20 such expeditions could have been so productive, let us at least grant the economy of the intelligent observer.

In the second place, let us consider a specific burden on air defense planners, such as the discrimination between ballistic missile warheads and their decoys. Earth-based systems are restricted by the lack of suitable data to discriminate nose cones from sophisticated decoys, and humans, regardless of their power of intelligent observation, cannot operate within the fractional time domain of electronic computers. There is a strong inclination to take man out of ground-based systems, and, insofar as it is feasible, this is the proper direction to take. Planners are handicapped, however, by the lack of information about the performance capabilities of the astronaut and so are reluctant to introduce yet another unknown into their concept of national defense. Could the astronaut provide a vital link in anti-missile defense system? Could the astronaut assist in the acquisition, tracking and discrimination of nose cone from decoys? Could the astronaut achieve what no computer or instrument is yet able to do? The lack of cogent information is unfortunate, but it is likely to persist unless steps are taken to conduct space-based experiments with man in the control loop. Successful discrimination by any route is difficult, but a solution is imperative and justifies the investigation of any method showing promise.

The "why" of manned space exploration can be answered in yet another way. During the past four years much information has been obtained about the environment of space within a few earth-radii of the earth. A number of dramatic and unexpected discoveries were made by means of early satellite vehicles, hampered even as they were by modest payloads, low equipment reliability and lack of information upon which to base the design of specific experiments. This very void of information about the space environment constituted one of the main reasons that striking scientific discoveries seem to pour in with each launching. These early experiments are the prelude to the drama to come. Even if we assume substantial relaxation of weight and space limitations, the attainment of adequate equipment reliability and dynamic range will become more difficult in the future, because of the inherently increasing complexity and sophistication of the experiments to be conducted. Simple discoveries are behind us; precise detailed experiments are in the offing, and they are always more difficult to perform. A natural evolution that will significantly increase the probability of obtaining worthwhile information is the inclusion of man in space flight. Man has the built-in reliability, perspicacity, adaptability, and redundancy needed to make these future voyages profitable as well as feasible. Furthermore, if we compare the physical burden of providing sustenance in order to avail ourselves of human productivity, against the physical obstacles of achieving man's functional characteristics in unmanned systems, man's role in space is definitely indicated.

Objectives of This Report

As space flight progresses, emphasis will shift from current preoccupation with methods of transportation toward the knowledge to be gained from explorations. Foremost among the questions to be answered by the exploration of space are those concerned with bioastronautics. A research and development program for manned space flight during the next two decades will serve both to establish human productivity in space-based systems and to stimulate the advancement of concepts of military action for exploiting human capabilities.

The reports in this series outline the information and ideas which must be considered in the formulation of a long range program aimed at manned exploration and use of outer space. In preparing them, we have tried to achieve these objectives:

1. An accounting of the men, money and skills invested in bioastronautics work by universities, not-for-profit and industrial concerns;
2. An evaluation of the usefulness of their effort to the Air Force program;
3. An appraisal of the research and development now in progress, together with a prognosis of technical accomplishments, and recommendations for research that recognize the magnitudes of the country's scientific skills, facilities, and manpower;
4. A development of several management plans, together with their strengths and limitations, that might be used by the Air Force Systems Command to provide guidance and liaison in the field of bioastronautics.

This report has been written primarily for those 360 organizations who supplied the data which made this inventory possible, and the many people in government agencies and private organizations who contributed their time, interest and advice to this undertaking. For these groups it is intended as a guide to research planning and budgeting.

To determine the present state of the art in astronautics, we began our work by studying the manned space system that exists today. Information about the National Aeronautics and Space Administration projects was gathered by interviews with Space Task Group and Headquarters professional staff. We also studied various plans and proposals that have been put forward for future systems. This information was gathered through conferences with individual members of the Space Science Board and with NASA, Air Force and Navy planning staffers, and through meetings with key persons in industries, universities and research laboratories. We also analyzed many published reports relating to the life sciences. This information has formed the background for the research recommendations discussed here.

This report has been prepared with the following ideas and assumptions in mind:

1. Detailed development, systems engineering and technical direction of space vehicle systems will be the responsibility of competitive industry.
2. Many of the problem areas associated with current manned space activities are not fundamental, but rather reflect the status of current technology. For example, the problem of providing a terrestrial environment in space is an operational problem and is dependent upon the current state of technology.
3. The engineering design of crew support systems for current programs is sufficiently supported by existing biological and behavioral knowledge. Problems exist, but many organizations have the facilities to refine basic data and to overcome problems specific to each space vehicle.
4. A long range program in bioastronautics must attempt to "turn the corner." It should be concerned with long range problems where technological developments promise little hope for relief, or where fundamental research could lead to new concepts in support of man in space.

RESOURCES FOR RESEARCH AND DEVELOPMENT

The human and material resources of this country are sufficient, not only to meet the demands of national security, but also, beyond any question, for it to assume a leader's role in the exploration and utilization of space. However, these first years of the space age have been ones of acquiring a capability in manned space flight. Achievement of the nation's objectives in space requires extensive scientific activity and accomplishment. The future of manned space research depends in an important way upon the close cooperation of federal agencies, both civilian and military, and of the scientific community.

ELEMENTS OF THE PROBLEM

In balancing accomplishment and requirement, both the federal agencies and the scientific community must know simultaneously what research is now under way and the intrinsic significance of this work for the nation's efforts. This appraisal is straightforward when considering grants and contracts given by the National Aeronautics and Space Administration and Department of Defense agencies. In fact, most of the planning documents used by federal agencies in this specific area of space activity are available, and organizations outside the government can be as well informed as those within the government. The converse is not true. There has been no assessment of the current life science programs of universities, not-for-profit and industrial organizations. As a result, there is no factual basis for the utilization and augmentation of internally sponsored research of these organizations. This uncertainty about the nation's resources has been greatly reduced by the completion of the present inventory which was designed to survey the internally funded or company sponsored research in the life sciences; to describe the staff engaged in this type of research; and, to obtain a listing of the major physical resources available for research and development use.

THE QUESTIONNAIRE - INVENTORY

A total of 460 questionnaires was mailed to 28 not-for-profit organizations, 60 universities, and 372 companies. Three hundred and sixty organizations replied to the request for information. We made a few bloopers, and one manufacturer of "space heaters" for houses and trailers quite naturally replied, "We are at a loss to understand your contacting this division. . . "

Approximately one-third of the organizations responding said that they did not have specialized knowledge, equipment or manpower that could be devoted to bioastronautics research, Twenty universities, foundations and institutes were placed in this category. These particular universities recognized that fundamental biological and behavioral research now in progress would contribute to the nation's man-in-space program, but stated that their contribution is indirect.

Almost a third of the respondents were organizations with a potential for research in bioastronautics, but without internally sponsored work. Although some of them now have NASA or DOD contracts, a majority do not. Included in this group are six not-for-profit organizations, 23 universities and 77 companies. Each has professionally trained personnel for research in the life sciences, and some have equipment to support their work.

Ninety-eight organizations, more than one-fourth of those responding, have internally sponsored research in addition to staff and equipment. This group includes seven not-for-profit organizations, 12 universities, and 79 industrial concerns. They are shown in the tabulation on the opposite page. In this tabulation the organizations are ordered in terms of the number of man-years of effort devoted to bioastronautics in 1962. The largest program is that of the General Electric Company, Missile and Space Division. The Garrett Corporation, Los Angeles, has the largest professional group working in bioastronautics, of which a little less than half work on company

Organizations Conducting Internally Sponsored Research

GENERAL ELECTRIC COMPANY
LOCKHEED AIRCRAFT/CALIFORNIA DIVISION
GARRETT CORPORATION
BOEING/AEROSPACE DIVISION
DALLONS LABORATORIES

PHILCO
INTERNATIONAL BUSINESS MACHINES
MARQUARDT CORPORATION
MELPAR
SAINT LOUIS UNIVERSITY

HUGHES/AEROSPACE GROUP
NORTH AMERICAN AVIATION/COLUMBUS DIVISION
LING-TEMCO-VOUGHT
UNITED AIRCRAFT/HAMILTON STANDARD DIVISION
ISOMET

GENERAL DYNAMICS/ASTRONAUTICS DIVISION
GENERAL TIRE & RUBBER/AEROJET-GENERAL
FIREWEL COMPANY
MARTIN/DENVER DIVISION
BOSTROM RESEARCH LABORATORIES

REPUBLIC AVIATION
GENERAL DYNAMICS/ELECTRIC BOAT DIVISION
BENDIX/PIONEER-CENTRAL DIVISION
MARTIN COMPANY/WEAPON SYSTEM ENGINEERING DIV.
NORTHROP/NORTRONICS DIVISION

UNIVERSITY OF MASSACHUSETTS/DEPT. OF ZOOLOGY
RESEARCH INSTRUMENT LABORATORIES
GRUMMAN AIRCRAFT
KENTUCKY RESEARCH FOUNDATION
ACF INDUSTRIES/ELECTRONICS DIVISION

DOUGLAS AIRCRAFT/LIFE SCIENCES SECTION
DEL MAR ENGINEERING LABORATORIES
LOCKHEED AIRCRAFT/MISSILES & SPACE DIVISION
RADIO CORPORATION OF AMERICA
NORTHROP/NORAIR DIVISION

STANLEY AVIATION
UNION CARBIDE/LINDE
BATTELLE MEMORIAL INSTITUTE
ASTRA
LITTON SYSTEMS

RESEARCH & AVIATION DEVELOPMENT
UNIVERSITY OF PENNSYLVANIA
GENERAL MILLS/ELECTRONICS DIVISION
INTERNATIONAL LATEX
ROSWELL PARK MEMORIAL INSTITUTE

AMERICAN INSTITUTE FOR RESEARCH
ELECTRO-OPTICAL SYSTEMS
IONICS
LEAR
LOCKHEED AIRCRAFT/GEORGIA DIVISION

NATIONAL RESEARCH AND DEVELOPMENT
REEVES INSTRUMENT
SPERRY RAND/SPERRY GYROSCOPE DIVISION
TEXAS CHRISTIAN UNIVERSITY
AVCO RESEARCH

BASIC & EXPERIMENTAL PHYSICS
R. E. DARLING
DUKE UNIVERSITY
INVENGINEERING
NEW MEXICO STATE UNIVERSITY

SCOTT AVIATION
SPACELABS
BELL AEROSYSTEMS
CORNELL AERONAUTICAL LABORATORY
LOVELACE FOUNDATION

MINE SAFETY APPLIANCES
PURITAN EQUIPMENT
BERGER BROTHERS
BLOCK ASSOCIATES
CONSOLIDATED CONTROLS

B. F. GOODRICH
GOODYEAR AIRCRAFT
ITT FEDERAL LABORATORIES
LITHIUM CORPORATION/FULTON-IRGON DIVISION
LORAL ELECTRONICS

MAXSON ELECTRONICS
ROBERTSHAW-FULTON
SIERRA ENGINEERING
STATE UNIVERSITY OF NEW YORK/DOWNSTATE
UNIVERSITY OF DENVER

FLORIDA STATE UNIVERSITY
HRB-SINGER
JOHNS-MANVILLE
NORTHWESTERN UNIVERSITY
WESTERN ELECTRO-ACOUSTIC LABORATORY

AIRBORNE INSTRUMENTS LABORATORY
AIRCRAFT ARMAMENTS
FLOW CORPORATION
FORD MOTOR COMPANY/AERONUTRONIC DIVISION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

NEW YORK UNIVERSITY
WEBB ASSOCIATES
ARMOUR RESEARCH FOUNDATION
WESTGATE LABORATORY
YELLOW SPRINGS INSTRUMENT

MAUCH LABORATORIES
APPLIED BIOLOGICAL SCIENCES LABORATORY
STRATO EQUIPMENT

funded projects. Four companies report an investment of over $1 million in equipment and facilities; 17 were in the $100,000 or over class. Boeing Company, Seattle, reported the largest number of professionally trained people with doctoral degrees; the American Institute for Research, Pittsburgh, Douglas Aircraft, Santa Monica, General Dynamics' Electric Boat Division, and Spacelabs each have more than 15 persons with this degree.

Specific data concerning the magnitude and relative emphasis given bioastronautics research by the 98 organizations will not be presented here, as the Laboratory agreed to protect the proprietary interest of the respondents. The Bioastronautics Office, Air Force Systems Command, has been given a quantitative description of the current research of the 98 organizations, together with a description of company projects and equipment.

THE RESOURCES

Successful research depends upon qualified people and depth of experience in a variety of fields. The first objective of the inventory is to obtain an over-all picture of the professional training of the research and scientific management staff now working in bioastronautics. The following data is an inventory of the men, money and materials invested in bioastronautics by 204 organizations. The tabular inset on the opposite page describes the manpower resources, of which the most interesting characteristic is their multidiscipline composition. The number of engineers now working in the field is nearly double that of any other professional group; and psychologists and chemists dominate in the doctoral degree category. Bioastronautics, therefore, does not belong to one profession, nor is it easily classified as a "hard" or "soft" scientific area.

The second largest category of 452 "others" needs clarification. Many of these people could very possibly have been included in professional categories. For example, some organizations included biophysicists, biochemists and radiobiologists in this group, when in fact they could have been placed in the categories of physics, chemistry and biology. Others, such as nurses, veterinarians, and pharmacists, could not be so categorized.

STAFFING SUMMARY

Profession	Bachelor	Master	Doctor	Totals
ANTHROPOLOGISTS	3	3	4	10
BACTERIOLOGISTS	47	23	49	119
BOTANISTS	10	9	11	30
CHEMISTS	182	92	134	408
ENGINEERS	831	388	78	1297
MATHEMATICIANS	36	53	14	103
NUTRITIONISTS	5	1	12	18
PHYSICIANS	1		93	94
PHYSICISTS	158	96	43	297
PHYSIOLOGISTS	41	27	59	127
PSYCHOLOGISTS	90	120	162	372
STATISTICIANS	23	11	6	40
ZOOLOGISTS	35	12	16	63
OTHERS	169	89	194	452
Totals	1631	924	875	3430

A staffing summary of NASA and DOD for the aerospace-related life science programs is shown in the next inset. Included are both military and civilian personnel. Although it is not possible at this time to break the totals into professional categories, it would not be surprising to find a distribution similar to that of the nongovernmental organizations. The data shows that the Air Force capability in the life sciences is the greatest source of competency now in existence within the government.

STAFFING SUMMARY

Organization	Bachelor	Master	Doctor	Totals
AIR FORCE	313	225	325	863
NAVY	110	70	161	341
ARMY	304	98	106	508
NASA	4	2	19	25
Totals	731	395	611	1737

Scientists and engineers must be supported. The number of technicians, aides, administrative and clerical personnel who are now supporting the technical staff of government and industry is slightly over nine thousand. Although this figure is open to interpretation, the respondents to the questionnaire reported that 8370 people were supporting the efforts of a 3430 man professional staff. The over-all ratio of support to professional personnel is approximately two to one.

Is an expansion possible? When asked to indicate the number of professionally qualified personnel of the research staff capable of working in bioastronautics but not now doing so, the potential was reported to be 6070. This is nearly double the number currently working in this area. The importance of this reply should not be overlooked. Although the figures given by some organizations in answer to this question were estimates, their total shows a large unused pool of professionally trained manpower for research and development.

Financial support for research and development in bioastronautics comes not only from federal agencies, but also from universities, not-for-profit and industrial organizations who earmark money and equipment for this purpose. A second objective of the inventory was the preparation of a baseline on the magnitude and distribution of this internally funded work. Of the 204 organizations currently working in the life sciences, 98, as mentioned earlier, report internally sponsored work. In order to make it possible to summarize the activities of the many different organizations, the recipients of the questionnaire were asked to define their work in terms of the research and development categories shown in the inset on the following page. A quantitative description of the internally funded work was obtained by asking for the number of projects, effort in man-years, and equipment and facilities costs (exclusive of buildings and other real estate).

Research and Development Categories and Instructions

Stress Tolerance

STUDIES OF THE EFFECT OF EXPOSURE TO THE ENVIRONMENTS AND STRESSES OF SPACE FLIGHT; NORMAL PHYSIOLOGICAL PROCESSES AND RESPONSES WHICH PROVIDE INFORMATION FOR UNDERSTANDING PERTURBATIONS CAUSED BY SPACE OPERATIONS. INCLUDE MOLECULAR AND CELLULAR SYSTEMS, TISSUES AND ORGANS, AND WHOLE ORGANISMS. ILLUSTRATIVE STRESSES ARE: RADIATION; ACCELERATION; AND, ACOUSTICAL, ELECTROMAGNETIC, AND THERMAL STRESSES.

Life Support

STUDIES TO DEFINE, CREATE, CONTROL, AND MAINTAIN AN ENVIRONMENT FOR SPACE OPERATIONS THAT WILL ENABLE PERSONNEL TO FUNCTION EFFECTIVELY FOR STATED PERIODS OF TIME. INCLUDE EFFORTS TO SPECIFY MAN'S GASEOUS, METABOLIC, TEMPERATURE, ACCELERATIVE, AND SOCIAL NEEDS; THE DESIGN, TESTING, AND EVALUATION OF LIFE SUPPORT, AND PROTECTIVE EQUIPMENT.

Human Engineering

STUDIES TO DEFINE THE LIMITATIONS AND CAPABILITIES OF MAN, AND TO CREATE A MAN-MACHINE SYSTEM WHICH WILL ENABLE MAN TO ACCOMPLISH HIS MISSION WITH MAXIMUM EFFECTIVENESS. INCLUDE MAN'S SENSORY RECEPTION OF INFORMATION; CONTROL PROCESSES AND RESPONSES; BODILY DIMENSIONS AND DYNAMICS; AND, BEHAVIORAL MECHANISMS THAT PROVIDE BASIC INFORMATION FOR PREDICTING AND PERFECTING THE PERFORMANCE OF INDIVIDUALS AND CREWS.

Crew Performance

STUDIES TO DEFINE QUALITATIVE AND QUANTITATIVE JOB PERFORMANCE REQUIREMENTS; THE DESIGN OF SIMULATORS; AND, THE SELECTION OF PERFORMANCE MEASURES BASED UPON TASKS TO BE PERFORMED DURING SPACE OPERATIONS. INCLUDE THE COMPOSITION AND ORGANIZATION OF CREWS; ANALYSIS OF PERFORMANCE DURING EXPOSURE TO ENVIRONMENTAL STRESS; AND, THE REFINEMENT OF PERSONNEL SELECTION TECHNIQUES.

Bioinstrumentation

STUDIES OF PROCEDURES FOR THE MEASUREMENT AND PROCESSING OF PSYCHOPHYSIOLOGICAL INFORMATION; AND, OF INSTRUMENTATION REQUIREMENTS FOR HUMAN OBSERVATION AND EXPERIMENTATION IN THE ENVIRONMENT OF SPACE. INCLUDE TECHNIQUES FOR THE STUDY OF THE INFORMATION HANDLING AND PROCESSING PRINCIPLES USED BY BIOLOGICAL SYSTEMS WHICH HAVE BEEN DEVELOPED IN THE FIELDS OF BIONICS AND BIOPHYSICS.

The magnitude and relative emphasis given each of the five research categories is now apparent. The fiscal summary inset shows over one thousand man-years of internally sponsored research and development work is being devoted to the nation's manned space flight program. Totals indicate that the magnitude of the research and development in bioastronautics is large and is growing larger. The number of projects, the effort and capital investment are higher in 1962 than in 1961. The percentage gain in some categories is large. The number of man-years invested in the human engineering and bioinstrumentation categories in 1962 was up 36% over 1961. The 1962 investment in equipment and facilities for research and development in the life support category was double that of 1961. The data in the inset show that 31% of the present manpower effort goes toward life support research, while only 9% is invested in the area of crew performance.

FISCAL SUMMARY

Research Categories	*Number of Projects*		*Effort in Man-Years*		*Equipment and Facility Costs (In Thousands)*	
	1961	*1962*	*1961*	*1962*	*1961*	*1962*
STRESS TOLERANCE	81	111	195.3	204.3	$1,498	$ 966
LIFE SUPPORT	188	196	280.5	323.6	2,224	4,412
HUMAN ENGINEERING	103	105	147.7	209.1	758	1,558
CREW PERFORMANCE	41	56	76.4	95.5	2,195	2,373
BIOINSTRUMENTATION	106	126	150.7	205.4	1,008	1,236
(Total not broken down)	-	-	5.1	30.0	20	3,017
Totals	519	594	855.7	1,067.9	$7,703	$13,562

What is the dollar magnitude of the manpower effort? Translation of man-years to dollars is achieved by using the cost-of-research index developed by the Operations Research Office, Johns Hopkins University. The index defines a technical man as "the professional scientist or engineer, together with his supporting technical, administrative and housekeeping staffs, and his machines and equipment, i.e., the man plus the overhead costs." The technical man-year cost is derived by dividing the annual volume of research

and development by the number of technical people in the organization. Group indices for industry, not-for-profit organizations, universities doing contract work, and federal government range from $25,000 to $35,000. The average cost of a technical man-year is placed at $30,000.

The data summarized on page 14 shows an expenditure within industry for bioastronautics research and development of $53 million. Twenty-one million is the total investment in equipment and facilities. For 1962 the manpower costs for internally sponsored research are $32 million. The 1961 investment was $6 million less.

Of the 98 organizations supplying the manpower and fiscal data on their internally sponsored research, seven were not-for-profit, 12 were universities, and 79 were industrial concerns. The missile/space companies dominate the internally supported research. Expenditures by not-for-profit organizations and universities are considerably smaller and in keeping with their limited financial resources.

Comparable data can be presented regarding the research and development work of federal agencies. The inset table gives a fiscal summary for aerospace-related life science programs.

FISCAL SUMMARY *

Organization	Research Budget 1960	1961	1962	Value of Installation
AIR FORCE	$23,256,664	$27,135,669	$27,149,000	$31,618,893
NAVY	5,955,000	6,476,000	6,536,000	30,018,546
ARMY	3,425,800	4,413,000	4,820,000	8,362,561
NASA	3,234,752	4,850,000	20,620,000	800,000
Totals	$35,872,216	$42,874,669	$59,125,000	$70,800,000

* FROM DOD AND NASA SOURCES

For 1962 the Department of Defense and the National Aeronautics and Space Administration invested almost $60 million in the life sciences. It is estimated that $40 million was for the support of internal programs. Capital investment in equipment was over $70 million, but this figure does not reflect space vehicle costs even though in some bioastronautics work the vehicle is the "installation." As was seen earlier, the magnitude of the bioastronautics work is large, but the rate of growth in the Department of Defense is less than in industry. NASA's growth rate is commensurate with the Mercury and Apollo programs. Money earmarked by nongovernment organizations in 1962 for internally sponsored work exceeds that authorized by NASA and Department of Defense for the same year.

THE TENOR OF THE FINDINGS

The accuracy of the inventory is of considerable importance. How well do the results of the questionnaire reflect the nation's resources? Although every effort was made to include all organizations in the aerospace and allied fields, some oversights did occur. One of the design partners in NASA's Project Mercury did not receive a questionnaire. Organizaticns with known capabilities failed to return the questionnaire. In one instance a company that is generally recognized as a leader in this field declined to reply because of the time required to survey their internal effort and sift out that part of bioastronautics not specifically directed toward space. The absence of these data in the inventory will result in an underestimate of the national resources.

This survey of nongovernmental research in bioastronautics has produced several important points for consideration. The capability of the 204 organizations is sufficiently large, much larger than hitherto realized, that cognizance must be taken of their resources and effective use. Beyond this capability, there is national enthusiasm on the part of those engaged in life sciences activities for space-oriented research, and many organizations not currently supporting bioastronautics report a willingness to enter all

phases of such research. It would be a great loss to the nation if such potential were not realized. However, it is scarcely possible to bring even a fraction of this potential into "blue-suit" capability or civil service laboratories, so that in order to make full use of it, any management program must have built-in flexibility and power to cover a broad range of technologies and their facilities.

The fundamental objective of science is knowledge. How can bio-astronautics, the science of man in space, add to our knowledge of the universe, of this earth, and of man himself? This is the basic question, for it is this scientific knowledge that is translated through technology to the improvement of man's economic and social wellbeing, and can be applied to military, medical and other uses. James M. Gavin has said, "There will come a day when rocket valves will be at work in the human heart - and we'll be thanking missiles that our hearts beat." It is not possible to discuss any of our own immediate problems without this ultimate goal in mind. Lest this be thought to be merely an idealistic evocation, one should keep in mind the enthusiasm that is currently pervading the scientific community at the opening of hitherto closed barriers to scientific inquiry. On every hand this new exploration is compared to the greatest explorations of the past. Response to the questionnaire of this survey alone indicates interest and enthusiasm in all quarters. Man is going to explore space as surely as he explored the hazardous uncharted regions of the earth, and as surely as he has attempted every venture into the unknown. Even if there were no military application for this country, such as the interests of security, defense or offense, we have, on the basis of ability, resources, and initiative, the moral as well as the political obligation of preeminence.

The next question is, then, what do we as a nation want to place first? In this matter it is unrealistic to separate one type of application from another. To put man into space in order to preserve national security is impossible without knowledge of what is necessary to put man into space for any purpose. In this stage of political development it is equally impossible to work only toward the ends of pure science and not consider how the fortunes of this country may best be protected by what we achieve through space exploration.

Perhaps the first place to begin, then, in framing goals for the national program of bioastronautics, is to assume that immediate projects under way are absorbing known data and technology. The problems of getting man to and around the moon, for instance, are in large part a refinement of known principles. It is the projects that are still on the drawing board, as it were, the speculative futures, that demand attention on the basis of long range planning. Thus, when we speak of long range goals, we are talking about innovation and exploration, whereas, planning for short range goals is a matter of taking what we already know and doing something with it.

If it is agreed to accept these fundamental observations, then it is apparent that in spite of impressive manpower and facilities, nongovernment research now under way is of an uneven and checkered composition. For the most part, emphasis is on the current technological state, and that in itself is narrowly constrained. This is not surprising when it is scarcely profitable to engage in research that will not have some application to a saleable end product. There is much duplication. Closed ecological systems, for instance, are currently supported by many organizations; yet, without knowledge of specific application to specific goals, there is no rational basis for deciding whether there is too much or too little duplication. Nor is there any basis for evaluating the distribution of effort among the five categories surveyed. Nearly one-third of our privately sponsored manpower is working in life support research.

In this attempt to evaluate the current state of research and development in bioastronautics, it has become apparent, then, that without a general statement of need on the part of those agencies responsible for goals in space exploration, few private organizations know where to place their efforts to best advantage. This observation was well reflected in the questionnaire response, in personal communication, as well as follow-up requests for evaluative information. There was a consistent expression of interest in, and approval of, a national assessment that would lead to a more effective distribution of effort, greater productivity and reward.

Almost every organization that was currently engaged in internally sponsored work, and many of those who expressed a potential in this area, indicated that their primary areas of interest were in no way limited to any one area of research, and it can be assumed that given the initiative, financial or purposive, they could undertake any activity necessary to meet scientific and military objectives.

Since we are considering where to place our best efforts, let us establish criteria, where possible, on the basis of what was indicated as fulfillment or lack by the questionnaire response, and further, on the basis of what is reflected by current scientific literature, and by discussion and soundings resulting from personal contact with researchers in this and related fields. These criteria must include as well, military and government sponsored research and development. Within this framework it is possible to say that current technology is meeting current problems in all areas, but that problems, some specific, some general, remain to be solved. That is, one criterion for future research is our present need to accomplish what has already been proposed and approved. The other criterion is our future need, based on what can be considered legitimate military, political, and scientific goals. To these ends there follows a discussion of several areas of space-oriented research, with a selection of topics whose common denominator is innovation. These are studies which may lead us beyond today's technology.

ON-BOARD RESEARCH DEVICES

Manned space vehicles will have many and varied missions. They will include the testing of materials, components and subsystems; research in the areas of physics and astronomy; and, behavioral and physiological investigations. The efficiency and utility of future satellite operations may be measured in terms of the quantity and complexity of on-board research. Many of the properties and phenomena of space vary greatly according to the place and time, and there are weak effects that cannot be detected by short flights. It is highly probable that the most important new results

to be obtained through space research will be unexpected ones. Thus, man's inherent flexibility can be an asset in looking for the unusual, and in conducting planned research, but the full exploitation of his productivity demands suitable apparatus.

There is no research or development work now in progress to provide the astronaut with tools for observation and experimentation. The Air Force Systems Command should consider the long range need for instruments that are small in volume and weight, robust and capable of operating reliably over long periods of time. A major goal would be to define a set of observational and measurement needs related to different missions and to compare these with what is available. The full utilization of current technology is of more importance here than technological advances.

From a physical point of view, an earth satellite can be used to observe only three elements of the environment. They are: photons, particles, and fields. Probes and satellites are currently being used to refine and extend man's knowledge about the solar system. As mentioned earlier, now that preliminary measurements have been taken, further work will inevitably become more sophisticated, and the achievement of adequate instrument reliability will become more and more difficult. The presence of an astronaut will significantly increase the reliability of complicated payloads, but painstaking development is needed to provide practical tools for the astronaut-scientist. Experience provides the guidelines in this work. Components should be selected to allow reasonable interchangeability with a minimum inventory. The function of equipment must be geared to potential adjustments and modification in space. To recall an earlier example: in the initial radiation experiments, a human observer could have readily seen that the counters were saturated and, on the first voyage could have performed on-the-spot modification to obtain the desired information. In this preliminary experiment, the cost of protecting man would have been comparable to the cost of the multiple shots needed to measure the radiation fields. Explorations of the future will be vastly more expensive, and repetition to correct for instrument failure or maladjustment will be much less tolerable.

Research in outer space will require certain prosaic developments. The visible part of the electromagnetic radiation (the photons) has scientific and practical significance. The photometric environment of space can be described in terms of luminance, contrast, and color. These factors characterize the appearance of the earth and its atmosphere, the moon, planets and stars. Quantitative estimates of the astronauts' visual environment could be made with a suitable photometer. However, not even the most sophisticated photometer on the market today could meet the design goals of reliability, accuracy and weight. We know how to build research equipment for space operation, we can meet our needs within current technology, and yet in this case the impetus for doing so is lacking.

MEASURING AND MONITORING HUMAN PERFORMANCE

During the past few years there has been a great volume of development work in bioelectrical instrumentation. For the most part this work has paralleled technological advances in solid state physics, microelectronics, and in the construction of micromodular assemblies. Problems still exist, but many organizations have the facilities to provide basic data for circuit design and to overcome problems specific to each space vehicle. Although considerable ingenuity will be required, the engineering aspects of this problem can be solved in a timely way with limited support from the Air Force Systems Command. The problem we want to examine involves something quite different. This country is short of the goal of making full utilization of the techniques provided by advances in electronics. The development of a stable, low noise amplifier at the turn of this century opened up an entirely new area of research for the physiologist. Electrocardiograms are standard clinical instruments today. The fact that EKG equipment can be built which will occupy less than one cubic inch volume is an interesting feat, but it is not an advance in physiological measurement. In what direction do these advances lie?

Blood Pressure Measurement

Current trends in blood pressure measurement follow two lines. One is the mechanization of the familiar cuff technique; the second involves measurement of the displacement of a surface artery. Another principle that has received little development attention is one in which external fluctuating pressure is applied until the slack is taken up in the vessel wall. The pressure technique involves the application of force and the detection of discontinuity in the force pressure relationship at the vessel wall. The pressure at which the discontinuity occurs is stored until the next sampling cycle. Sampling rate is set to be many times the pulse frequency. The new sample is combined with the one taken previously and blood pressure is read directly. Further studies are needed on the elastic characteristics of surface vessels under these conditions of measurement and development work is required on servo-controlled force-balance transducers used to carry out the measurement.

Measurement of Blood Volume and Distribution

Measurements of blood volume and distribution using skin sensors do not offer much promise of success. Internally implanted sensors, permissible in animal experimentation, make these measurements easy and direct, although equipment to carry out such work in space would need engineering improvement. New blood flow devices look promising, especially those that have remote electrical balance features that do not require occlusion of the blood vessel.

Detection of Bone Demineralization

Bone demineralization may be a problem of long term null gravity. It is premature to speculate whether or not such changes should be looked for during space voyages or held in abeyance until the astronaut returns to earth. The significance of these changes and their measurement warrant further study. From an engineering point of view attention should be given

to the possibility of using acoustical techniques for determining the relationship between resonance frequencies and mechanical loss. The technique could be used to relate change in bone condition to these measured parameters. It is assumed, of course, that the use of conventional techniques such as X ray are inappropriate for the space environment.

Biochemical Analysis

The most significant biological changes uncovered during the two flights in the Project Mercury program were biochemical. Pre-flight and post-flight analysis of body fluids, made under laboratory conditions, provided a quantitative index of the physiological price paid by the astronaut for this venture. In the context of long-duration missions, critical biological information requirements are more likely to be in the field of biochemistry than in the conventional external physiological measurements. Very little progress has been made toward this goal, and the usual laboratory equipment and reagents could not meet the design goals of reliability, accuracy and weight. Development work along these lines should be undertaken.

The newly available microchemical equipment for the common blood and urine tests (glucose, urea, chlorides, etc.) show what can be done with a determined effort to simplify equipment and reduce the amount of sample needed. Ease and simplicity of use, reliability and freedom from laboratory plumbing are attractive features which bring us closer to being able to use this type of test on board. However, some of the more meaningful measures, such as epinephrin/norepinephrine levels in the blood, offer greater technical difficulty, calling for considerable research and development. Also all accessible body fluids should be considered as sites for biochemical indicators, and here we should include urine, saliva, sweat and expired air.

Summary

Bioinstrumentation will continue to parallel technological advances in solid state physics and microelectronics. As a result, the bioinstrumentation of the future will be small, light weight and accurate. Development work is necessary if the information requirements of the military and scientific community are to be met. Technological advances in this field do not consist of replacing one instrument by a better engineered instrument, but by a continuous expansion in the variety and complexity of such devices. This expansion is not likely to take place without considerable encouragement.

MORE EFFECTIVE USE OF COMPUTERS

The introduction of a new and valuable tool into science and technology does not guarantee its widespread use. Diversity and specialization have created problems of isolation of techniques, so that those who are trained in the development and use of the new tool often come from disciplines different from those whose problems and data are particularly suited to its utilization. The advent of digital computers illustrates this observation. Bioastronautics has emphasized the sensory equipment for data collection and, for the most part, neglected computer simulation and analysis of biological systems, a tool relatively unfamiliar to most scientists who may be aware of the concept but lack skill in its exploitation. The future of computers in bioastronautics is in the areas of analysis and simulation.

Measurement by Mimicking

Measuring and monitoring the performance of the astronaut is a much discussed problem in biomedical laboratories. There is a general feeling that the measures in current use are not sufficiently sensitive to performance processes. Sometimes we observe changes, and at other

times we get nothing, although in both cases a positive result is expected. The problem here is one of getting "inside" a perceptual motor process to see how the factors contribute to performance capability change. For example, we know enough about the engineering properties of man to write a linear differential equation that will approximate his performance in closed loop tracking with remarkable success. In one case the pilot could not discriminate, on the basis of the effects of control response on the display, whether he or his computer analogue was in control at any given time.

Here, then, is an idea for measuring and monitoring performance. Suppose we continuously adjust the analogue of the man to match his performance. We are now able to look not only at his over-all performance but also at how this performance was achieved. Adjustments made to the analogue reflect the weights assigned by the astronaut to the magnitude of higher derivatives of errors in tracking. In other words, we mimic his performance on a computer while he is performing and note the changes that must be made to the computer to effect simulation. Changes in the simulation can then be related to the stress (fatigue, acceleration, hypoxia, etc.) imposed on the astronaut.

Computer analogues of man can also be developed which mimic his problem solving and complex information processing behavior. In mimicking problem solving, the range of alternative solutions considered, the sub-goals generated when no direct solution is possible, and the depth to which a line of reasoning is explored before it is abandoned, are some of the variables which may be programmed. By adjusting these variables to produce a program which duplicates man's over-all problem solving behavior under various conditions of stress, we can determine in detail how these conditions affect the processes underlying man's higher mental functions.

The development of heuristic programming techniques for the simulation of problem solving and other intellectual functions of man is in

progress at several institutions. Heuristic programs can currently mimic a man's behavior in selecting concepts for classifying patterns, proving theorems in logic and geometry, and playing chess. Programs are being developed which duplicate man's behavior in learning to control unfamiliar apparatus and reproduce the step-by-step behavior of a composer writing a fugue. These techniques should be readily adaptable to mimicking the problem-solving and decision-making tasks of the astronaut. Measurement by mimicking needs development and experimental verification in its application to bioastronautics.

Selection of Astronauts

In the selection of future astronauts, computers can handle the analysis of the large body of psychological and physiological data collected on each candidate, applying powerful statistical techniques to data previously left to the uncertainties of clinical evaluation. The adaptation of these selection procedures to specific assignments, such as the performance of biological experiments in space, could readily be incorporated into a general computer program for astronaut selection.

Simulation of Homeostatic Processes

The study of the homeostatic processes of man could be carried out by computer simulation of important biological systems, drawing upon engineering studies of adaptive control systems. An improved understanding of these processes will be necessary for the development of artificial changes in them, to extend the range of environments in which man can function. The effects of proposed surgical and pharmacological changes in the astronaut, on his entire physiological functioning, may be examined by computer simulation.

Selection of Physiological Measures

During space flights, computers can be used to reduce the amount of information that must be collected and transmitted, and, as in present

applications, to process the data that is transmitted to the ground station. Standard physiological measures, such as blood pressure and pulse rate, have evolved over the course of medical practice to their present status. Such measures retain some degree of redundancy and specificity, and are probably not the optimum set of measurements for collection and transmission of physiological information during space flight. By subjecting the measurements currently in use to more powerful statistical analyses, such as factor analysis, a more orthogonal and perhaps more meaningful subset of physiological measurements can be selected.

Analysis of Physiological Data

The processing of that data which is transmitted to ground computers will require the most advanced analytic techniques, in order to produce a maximum return in information for each investment in space flight. While such processing is currently the primary application of computers to bioastronautics, this application can be expanded considerably.

Astronaut Training

More rapid instruction of astronauts in the performance of their many inflight tasks could be made possible by the use of teaching machines. Simple devices are currently being tried out in school classrooms, and experimental work has been performed using a high speed digital computer as the instructor. With further developments in computer generation of visual displays, the unusual visual environments which will be encountered in space can be realistically simulated, just as acceleration profiles are simulated today by computer control of centrifuge motion. A combination of teaching machine techniques with realistic simulation should prove useful in training astronauts for the complex space missions of the future.

Computer Applications

Further application of statistics to physiological data, through the use of high speed digital computers, is needed. Several investigators

have shown how the application of the most basic theorems of probability for example, could assist in medical diagnosis. An interdisciplinary effort among physiologists, physicians, statisticians, and programmers should result in programs capable of extracting the most meaningful results from the large amount of physiological data which is being, and will be collected in the bioastronautics program.

Analysis of physiological data will be facilitated by the development of a pattern recognition capability in computers for use in data reduction. This capability would be useful, for example, in sequential microphotographic analysis. Motion picture photomicrograms of important biological processes, such as pictures of differentially strained tissues, can be used to trace sequences of events, by feeding this pictorial data into the computer and automatically tracing cellular growth and interconnections.

The need for centralized information processing, storage and retrieval facilities has been recognized in many disciplines, and bioastronautics would certainly benefit from such a facility. The central computer in this facility would contain a library of data processing programs, ready for the analysis of new bioastronautics data. The results of previous analyses would be stored and immediately available to research workers. In addition, data, as it is received during a space flight, could be compared to previous results and immediate decisions reached on further data collection during that flight.

Programming

With the great strides taken in the past few years in computer hardware, there has been a noticeable lag in computer "software," or programming technology. This lag manifests itself today in frequent decisions to use slower, more costly, and less accurate information processing methods to avoid the difficulties of computer programming. While recent developments in compilers, e.g., FORTRAN, have made programming much faster and easier, it can still be a tedious, time-consuming process. In addition,

most compilers are usable on only one class of machine. The adaptation and development of a universal, easy-to-use programming language such as ALGOL-60 is a recognized goal among computer programmers. For maximum success, such a language should be redundant and self correcting, so that minor efforts in its use do not prevent the solution of the problem being programmed. Future emphasis on developing a simple "medical ALGOL" computer compiler language would be of great help for bioastronautics.

One possibility, which has been investigated for several years at the Massachusetts Institute of Technology Lincoln Laboratory, is direct communication in the English language. While English has not been used as a programming language, it has been used successfully as an input language. Using the Lincoln Laboratory program, questions in everyday English, concerning a restricted subject matter can be asked of the computer. The machine performs a syntactic analysis of the sentence and a semantic analysis of the significant words, arriving at an internal specification of the desired data. It then locates the answer among its stored data and prints it. Many of the applications of computers to bioastronautics, e.g., the use of a computer to control the collection of physiological data during a space flight, would benefit from a capability for direct, immediate reprogramming using English commands, and information retrieval using ordinary English questions and answers.

Computer Hardware

While computer hardware development is proceeding at a rapid pace, certain specific hardware needs arise in bioinstrumentation. Most of these are similar to the special requirements of airborne computers in general. Computers to be used in data collection or preprocessing in space vehicles will have to meet stringent size, weight, and reliability requirements. Some of the developments in computer components which may help achieve these goals are the following:

Higher Speed Transistors   Thinner base regions to keep the carrier transit time low will be developed soon to achieve higher speeds. The fastest present electromechanical jet etched transistor or mesa transistor with 10 micron base thickness will be reduced to 1 micron by epitaxial growth techniques. Distant future research may develop metallic film structures which approach 0.01 micron thickness, by tunneling through oxide layers.

Tunnel Diodes   Because tunnel diodes have inherently high reliability, and good stability of performance, they show promise for spaceborne computers. Tunnel diodes also have temperature and radiation resistance exceeding that of other semiconductor devices. The tiny size, ultra-low weight, and unusually low power requirements allow the use of multiple logic which raises computer reliability through circuit redundancy. The tunnel diode appears to have an assured future in high-speed airborne computers, as both a memory and logical element. Tunnel diodes are now available that can supply clock rates of 30 mc/sec and based on present developments, tunnel diode computers with 1000 mc/sec clock rates are predicted.

Thin Film Cryotron   This is another promising logic and memory device for airborne computers. The advantages are nanosecond switching time, low cost, and small size (up to 10,000 elements per square foot). The need for cryogenic cooling equipment may be minimized by the development of miniature, closed cycle cryogenic computers. The thin film approach appears to be a logical method for increasing the number of elements. A theoretical understanding of thin film physics must be developed, since past work has been largely empirical.

Organic Semiconductors   The investigation of organic materials in the use of semiconductors is so new in this country that no estimate of the applications can be made until the properties are defined. The usefulness in transistors looks questionable since the mobility of charges

appears generally low. However, it should be noted that included with 50 patents bought from Russia by this country was one on a polyacrylonitrile organic semiconductor which was reported to have a temperature stability of 700°C. Previous investigation of organic materials showed them to be unstable at relatively low (100°C) temperatures. Possibly there are some applications as radiation detectors, and as photosensitive devices. The area seems largely unexplored, and, therefore, possibilities are unknown.

Magnetic Logic Magnetic logic elements have 10,000 times more radiation resistance than semiconductors and diodes, and can also be reliable and cheap. Low operating speed and high power drain are disadvantages. The parametron, ladic, and transfluxor all operate below a megacycle, and power dissipation is related to speed. Square loop magnetic films of Permaloy have the advantage of high packing density, resistance to high temperatures (200°C), and nanosecond speeds. However, progress on logic must be made before production computers can be built.

Pneumatic Components The reliability of pneumatic control mechanisms is well known in the industrial control field. Only recently have pneumatic components been taken seriously for airborne and space computers. The advantages are high reliability, broad operating temperatures (100°F to 2,000°F), insensitivity to radiation, and compact, rugged operation. Already gas-powered flip-flops have been built with 6,000 switches per cubic inch, and with 10 microsecond switching time. Electric to pneumatic conversion is easily accomplished, and the power supply requirements are much simpler than those of solid state computers.

Neuristors The nerve type network components which are under development at Stanford Research Institute open an entirely new field of computer organization and processing. As a logical element, the neuristor appears to have the advantages of high flexibility, through readily change-

able organizations to match specific problems. However, practical components remain to be developed, although a few companies are undertaking this work.

General Other hardware needs arise in the input-output processes, and are common to many computer applications. In addition to programming systems which will accept ordinary English, input devices which will accept printed, handwritten, and verbal material are necessary for rapid programming and information retrieval.

Finally, if the greatest possible benefits to bioastronautics are to be reaped from these developments, physiologists, physicians, psychologists and engineers must be trained in computer applications. The lack of such training currently prevents many scientists from benefiting from computer technology, and this problem will become more serious as computer developments progress.

ENGINEERING THE ENVIRONMENT

In the formal sense, man's requirements for a hospitable environment are the same as those placed on equipment, if the equipment is to operate at a specific level of reliability. The maintenance of a biological equilibrium in a closed vehicle is predicated upon the production of a synthetic environment that provides, for example, adequate blood pressure at eye level; that conforms to man's metabolic processes; that protects him from radiation; and that satisfactorily resolves problems of long confinement in a restricted environment. In providing for the highest level of human reliability, the guideline so far has been that the synthetic environment will be essentially equivalent to the terrestrial environment. The problem of providing such an environment in space is an operational problem and is largely dependent upon the current state of technology. Therefore, many of our problem areas associated with space travel today are not really fundamental to life support, but rather reflect the status of our current technology. Variations from terrestrial conditions are

tolerated in Mercury, Dyna-Soar, and Apollo, but these solutions have been advanced because of our inability, at this time, to provide the terrestrial environment. These departures will be solved by clearly foreseeable advances.

At the outset of our study we took the position that the engineering design of life support systems for current programs, at least through Project Apollo, is sufficiently supported by existing physiological knowledge and existing technology. During the course of the study and in many laboratories which were visited, this proposition met little opposition. If new research is needed, then, what direction should it take?

Oxygen Concentration

There is active and interesting research in both high and low concentrations of oxygen for human use. Judicious encouragement of this research is warranted, to permit us the freedom, at some future date, of choosing a partial pressure of oxygen different from its normal partial pressure of air at sea level. In this brief discussion, higher concentrations than normal are considered in light of some new basic research, while low concentrations are briefly mentioned.

In high concentrations of oxygen (e.g. 100% oxygen 250 mm Hg or any gas mixture where the partial pressure is higher than 400 mm Hg), there arises the question of oxygen toxicity. The toxic effect of oxygen appears to be of two kinds, one of which is apparently toxic to tissues, and the other involves a mechanical event in the alveolus.

Chronic exposure to pure oxygen in the range of 250 to 800 mm Hg leads to respiratory embarrassment, both in animal and in man. In human experiments the observation is one of partial pulmonary atelectasis,

as seen, for example, in aviators who have been breathing oxygen by mask for a prolonged period of flight. Mild atelectasis is also seen in the sealed cabin experiments in which essentially pure oxygen atmospheres are used at 250 to 500 mm Hg. No human deaths have been reported, but many of the deaths in laboratory animals may well be due to at least an initial atelectatic process.

The mechanism of atelectasis seems quite straightforward. The lack of the inert diluent, which in air is nitrogen, invites the collapse of alveoli, especially in those parts of the lung which are not active and well ventilated. Alveoli stay open through a rather precise balance between forces tending to keep the alveolus open and forces tending to collapse the alveolus.

The forces which keep the alveolus open have been made clearer with the new knowledge in pulmonary surfactants. The alveolus would not stay open without the considerable surface tension lowering effect of a material which has now been identified as a mucopolysaccharide. The gases in the alveolus - oxygen, nitrogen, water vapor and carbon dioxide - plus the elastic and mechanical properties of the alveolar wall, are not by themselves sufficient to balance the forces tending to collapse. Surface-active materials, or surfactants, have been isolated and their forces measured. (This active research area was the subject of the annual Bowditch lecture, given by Dr. John Clements at the Fall Meeting of the American Physiological Society, 1961).

The forces tending to collapse the alveolus consist of tissue fluid pressure, the dynamic pressure of the pulmonary capillaries (which is higher by a considerable amount than the static pressure measured in pulmonary capillaries), and the strong surface tension forces present in any small liquid bubble.

It would appear that in many of the animal experiments where there has been a prolonged exposure to pure oxygen at tensions between 250 and 800 mm, death has occurred through a cycle starting with spotty atelectasis,

followed by pulmonary edema in the collapsed alveoli, and these became foci for bronchopneumonia.

The implications of this knowledge are clear: astronauts, who would normally be rather quiescent and not doing much pulmonary work, especially if the gas mixture is less dense than we are accustomed to on earth, would be in danger of developing partial atelectasis. To overcome this, frequent exercise or perhaps a shot of carbon dioxide to stimulate deep breathing would be corrective measures. However, before we recommend therapeutic procedures, more research into the nature of oxygen toxicity, both of this chronic and also of the acute variety, seems clearly indicated.

In the matter of low oxygen tension, there has been much interesting work on acclimatization to supplement the classic work on native populations in the Andes and Himalayas who live at altitudes above 10,000 feet. Particularly one should mention the work of Balke and of Pugh and others relating to physical conditioning and acclimatization at high altitudes. However, it is time that we encourage research into basic physiological mechanisms in hypoxia and adaptation - questions dealing with transport and tissue utilization of oxygen.

Role of Nitrogen

Perhaps the most important role of nitrogen is a pressurizing effect in the alveolus. This role is a passive one, and any other inert gas with similar properties should do as well.

Actually these gases - nitrogen, helium, argon, xenon and krypton - are inert metabolically, but they have a pharmacological effect. Nitrogen at several atmospheres pressure becomes a narcotic; helium also has a narcotic effect, but at a much higher level of pressure.

The metabolic inertness of nitrogen has been questioned. A Russian paper by M. I. Volski in 1960 concludes that the chick embryo

fixes nitrogen from the atmosphere and needs this source metabolically to complete its growth.

Two papers have been given at meetings of the American Physiological Society by Shannon Allen. Again working with chick embryos, Allen finds that nitrogen lack, whether at reduced pressure or at normal pressure using another inert gas as a diluent, causes incomplete development or failure to develop further in the chick embryos. Allen is also led to suspect nitrogen lack as playing a part in the human clinical condition of retrolental fibroplasia, where high concentrations of oxygen are used in incubators, especially for premature infants.

These reports on the active role of nitrogen are preliminary, and the data cannot be applied now in bioastronautics. However, the general question of the role of inert diluents in an atmospheric gas mixture is one which needs attention and research.

Carbon Dioxide Levels

The partial pressure of carbon dioxide in normal air is less than 1 mm. However, in submarine atmospheres the partial pressures may rise to 8 or 15 mm, and it has been shown by Schaefer and others at the Naval Medical Research Laboratory in New London that this is a level to which people can adjust using normal physiological compensations. The question has been raised, however, as to whether this physiological adjustment is totally without stress.

On the other hand, it has been known for some time that carbon dioxide in an artificial gas mixture has therapeutic advantages. The blowing-off of carbon dioxide, as in hyperventilation, leads to the difficulties associated with alkalosis. There is a suggestion that carbon dioxide in the gas mixture could help prevent pulmonary atelectasis by insuring ventilation of normally inactive alveoli. And finally, there is the effect of carbon dioxide on cerebral blood flow, a vascular dilation which might be of considerable value.

The enhancement of cerebral blood flow by carbon dioxide is so pronounced that its use in artificial atmospheres has been advocated by some (for example, C. J. Lambertson and co-workers at the University of Pennsylvania). When the end result of our physiological modes of support is adequate tissue oxygenation, and the most critical tissue in a performing human being is the central nervous system, any measure which specifically supports these functions is worthy of consideration.

General Metabolism

In an orbiting space vehicle, the crew constitutes an important heat source. Maintaining thermal balance of the space vehicle is important both for the human occupants and for the equipment. The human heat source is an inconstant one whose character needs to be further defined and precisely described. General metabolism or over-all heat production varies with the state of activity of the man, and changes particularly during periods of physical work.

The system for maintaining thermal balance from minute to minute must be designed to accept the average level of best production plus its transient variations. The classic technique for achieving this knowledge is calorimetry.

Indirect calorimetry, which utilizes the continuous measurement of oxygen consumption and carbon dioxide production, has been of value largely because the equipment necessary was less complicated and less restrictive to a working man. However, the ideal would be the direct measurement of heat production from a man with a sensitive and non-confining calorimeter. Even better, calorimetry, both direct and indirect, could be done during the first space missions as an experimental procedure, to truly establish levels of heat production and requirements for oxygen.

There is a possibility that a direct calorimeter, in the form of a suit very much like a full pressure suit, can be developed; with the

clothing techniques available today plus the techniques in closed atmosphere regenerating systems, the development of a suit calorimeter appears to be possible. The development of a suit calorimeter for ground use alone would be an important step; a suit calorimeter which could actually be flown, as a final step, would be a very exciting prospect.

Finally, as an item of research, it will be interesting to be able to measure with precision the actual metabolic effects of prolonged zero gravity. It might even be possible to use direct or indirect calorimetry as a precise indicator of increased activity level during an exercise regime.

Metabolic Balances

In the completely closed environment of a space cabin, the individual metabolic balances or cycles assume a great importance from the control standpoint. On a large scale one thinks in terms of the carbon cycle, the nitrogen cycle, and mineral and water cycles. The goal of providing for a complete nutrient cycle combined with gaseous cycling of oxygen and carbon dioxide through the use of algal cultures is a very active field in research. However, there are problems which must be met, both from the engineering standpoint and probably also from the standpoint of deeper understanding of physiological mechanisms.

As an illustration of the kind of research which might in the long run contribute to the problem of the complex balances in a completely sealed cabin, consider the so-called "closed aquarium." In this situation, marine forms, both plant and animal, are in at least a temporary balance which can be maintained for weeks at a time without adding or subtracting anything from the glass-enclosed medium. Light must enter to form an additional source of energy, but the gaseous exchange between plant and animal, and apparently the nutrient exchange, is reasonably stable and under control. Detailed understanding of, for example, the cycling of the sulphur or manganese or amino acids in such an environment is so far lacking; yet in even this simple situation detailed under-

standing should add a considerable insight into the possibly more complex relationship between man and his environment in a sealed space. We need to know a great deal about the natural buffer mechanisms which prevent excessive buildup of any potentially toxic substance, or the loss of a vital element in some chemical blind corner.

One other illustration of the need for research in metabolic cycles can be found in the consideration of water cycling. It can be shown from experiences in balloon gondolas and some other sealed cabin situations that water vapor as a gas is potentially dangerous in that thermal balance is seriously embarrassed by excess levels. Dehydration is another aspect of this problem, although present-day experience seems adequate to at least set the design limits for the amount of water which must be ingested every day. Nevertheless, experience in the two-man simulator at the School of Aviation Medicine at Brooks Air Force Base runs into the problem of unexplained weight losses which have the appearance of changes in insensible weight loss as a result of the decreased total pressure used in the runs so far. So, in a relatively simple cycle, that of water balance, the problems and interactions are by no means completely understood or easily controlled. How much more complex must be the total ecological understanding of the multiple components that are necessary for human life for very prolonged periods of time.

Specific research projects are not suggested here, nor do we mean to underemphasize the importance of the toxicological studies which are being carried out both in the nuclear submarine atmosphere program and in the materials testing program carried on in the design of a space vehicle. The kind of research, however, which we do recommend is aimed at basic biochemical and physiological understanding, which in time will be the basis for engineering solutions.

Thermal Balance by Radiation Pathways

The subject of human thermal balance takes an unconventional twist when considering man in a space suit outside the space vehicle,

as for example when doing repairs or maintenance around an orbital vehicle, or when exploring the lunar surface. Normally we consider a man in his clothing as exchanging heat with the environment through convection, conduction, radiation and evaporation. In the space environment, the thermal radiation pathway is the only avenue available for thermal exchange with the environment.

Certain engineering studies have pointed to the possibility of achieving thermal balance of man in the space environment through judicious adjustment of the absorptivity/emissivity ratio of the external surface, such that the man is essentially isolated from the environment and the whole heat balance problem is one of dissipation of internally generated heat. However, this calls for a stored heat sink or possibly an energy source, depending on whether the man is in constant sunlight or constant shade.

Further design studies will require some physiological research on human heat exchange via the radiation pathway. There is only preliminary work available in the literature of environmental physiology, and radiation exchange across large radiation gradients has never been adequately explored.

It might be useful also to consider using radiation exchange within the space capsule as a means of losing body heat, so that the problem of control of water vapor, for example, was not so critical. If one lost control of water vapor, the matter of accumulating body heat could be handled via a radiation sink. This idea is attractive because it would be fairly straightforward to arrange for a cold wall in the space vehicle by having a surface of the outer wall with high absorptivity and low emissivity. Again, the physiological background for this sort of engineering solution is extremely limited. Research in this direction is called for.

Radiation Damage and Protection

Presently known corpuscular radiations in the astronomical environment of Earth consist of: (1) galactic cosmic radiation; (2) cosmic radiation of solar origin - primarily protons; (3) interplanetary plasma; (4) radiations trapped semipermanently in the earth's geomagnetic field. The interplanetary plasma is usually dismissed as being of relatively low energy and a small problem. Trapped corpuscular radiations make up the Van Allen belt, and some of this energy can be handled by mass shielding. The exposure of astronauts can also be limited in time by rapid transverse passage through one or both of these areas of trapped radiation. Orbits around the earth would be located either above or below the belts so as to reduce long-time exposure. Active shielding, e.g. by electromagnetic fields, is not yet feasible, but offers hope for future development.

The primary attention currently, then, is directed toward cosmic radiations, whether of solar or galactic origin. This type of radiation is extremely difficult to reproduce on earth, and therefore it is difficult to establish the relative biological effectiveness (RBE). First reports are appearing from the two linear accelerators in this country on the effects of heavy particles accelerated to energies of millions of electron volts. This energy level is still far smaller than represented in the cosmic radiations. The preliminary information on RBE is interesting, but extrapolation of these results to the higher energy levels is somewhat risky. This is one situation where apparently the space platform will be necessary to conduct the definitive experiments. Meanwhile, the work being conducted with the heavy ion linear accelerators (HILAC) at Yale and at Berkeley should be encouraged and continued.

It also seems important to pursue further studies into the mechanism of biological damage by ionizing radiations. For example, it is probably pertinent to ask whether the effects of ionization in tissue ascribed to the formation of free radicals is noticeably influenced by

physical conditions such as cold, as produced in hypothermia and by various drug treatments which could be used to reduce the effect of exposure during a transient period. Related to the research in mechanisms of biological damage is the elucidation of the "time factor" in ionizing radiation as discussed by H. J. Schaefer at the Aerospace Medical Association Meeting in April 1961. It seems that for certain kinds of ionizing radiation, the biological effect is reduced if the rate of administration is diminished. For example, a dose of 150 rem (radiation equivalent man) delivered in one day could reduce the performance capability of an astronaut for one or two days following; but the same dose of 150 rem spread over a 10-day period would probably not produce any clinically identifiable damage. Unfortunately, Schaefer points out, the time factor seems to work in reverse in the case of damage from small doses of heavy nuclei. It would be most interesting to find explanations for these observations in terms of the mechanism of biological damage due to ionizing radiation.

Finally, the topic of genetic damage from radiation during space flight is one which, although speculative at present, should be included in research planning for the prolonged missions of the far future.

A distinct experiment has been suggested during a conversation with Per Scholander at the Scripps Oceanographic Institute along the lines of the ancient notion of Arrhenius that life is broadly seeded throughout our solar system. There is speculation concerning the ability even of resistant spores to survive the rigors of space. The hard vacuum (equivalent to extreme dehydration), the extreme low temperature, and finally the matter of ionizing radiations, are the three obvious environmental components which would make survivability seem unlikely. However, we know that spores exist and are viable in very high altitudes in almost any part of the world. Desiccation and extreme low temperature are possibly conditions which would enhance the survivability of simple micro-organisms. The largest question mark is the matter of ionizing

radiations. The suggested experiment, in its simplest form, would consist of exposing resistant spores to hard vacuum here in earth laboratories; to cold temperatures such as that of liquified helium; and finally, exposing such material to various kinds of radiation. Viability could then be examined with culture techniques.

EXTENSION OF HUMAN CAPABILITIES

In the not too distant future men will be confined to space vehicles for months and possibly years. In the exploration of space the endurance of the human may be a serious limitation. A great deal of research is being undertaken to resolve this problem and it is impossible to predict what, if any, the ultimate limitation might be. The outstanding experimental work in this area is that of Lockheed Aircraft, Marietta, on the effects of different work-rest cycles on man's performance. Long mission times and isolation are problem areas for which there are no technological solutions at this time. The possibility of maintaining man under environmental conditions basically different from those of the earth deserve priority in long range planning. What extensions of earth-based human physiological and behavioral capabilities might be called for?

Study and Prevention of Difficulties in Null Gravity

In the null gravity field, our present predictions are that for prolonged periods of stay, meaning beyond one or two days, there will be loss of muscle strength or muscle atrophy, demineralization of bone, and a reduced responsiveness of the circulatory system to physical stress. These are all extensions of clinical experience with bedridden patients. The effects, at least in terms of circulatory responsiveness, have been confirmed as test situations to bring out the effect.

The mechanisms of muscle atrophy from disuse and of demineralization of bone during disuse are not all well understood. Research in

this general field will be of value. The same may be said for circulatory responsiveness to stress.

A number of empirical measures have been proposed for the combatting of these several effects. The most prominent of these is a carefully chosen and graded regime of muscular exercise. Other means, however improbable-sounding to earthbound imaginations, should at least be considered; for example, electrical stimulation of muscle as is done in certain clinical conditions now, conscious control of what are usually thought to be automatic functions such as the control of the heart rate, and biochemical adjustments of the diet to combat demineralization.

Since we will not have enough manned space missions to test all of the proposed methods for overcoming these effects, it is clear that a research program using bed rest or water flotation to simulate the physical environment would be useful.

Uses of Null Gravity

While null gravity is usually regarded as a hostile or threatening condition, it may be worthwhile to consider it as a possibly useful situation to be taken advantage of.

One such usage is the possibility, based upon the results of recent water flotation studies,that during the hypodynamic state there is a reduced need for complete rest or sleep. (Actually a related suggestion appeared several years ago in an article by John Lilly.) It may be that a much longer work period and shorter rest period can be planned for whatever the activity cycle may be in a space mission. Obviously this would have great influence on the number of crew members needed in a given mission to perform a given amount of work. The longer the work period, the shorter the rest, the fewer the people one needs.

Since no muscular effort is needed to maintain posture in zero g, physical work performed by crew members can be included as part of

the auxiliary power available for the vehicle. A highly trained athlete is able to maintain a level of work output equivalent to one hp for hours at a time. Sedentary people, unfortunately, have difficulty maintaining a level of one-quarter hp for more than 15 or 20 minutes. Within these limits, it might be possible to expect crew members to produce levels of approximately 1/2 hp (370 watts) fairly steadily, using all the members of a multi-man crew in relay fashion.

Study of Sleep and Fatigue

The usual earth patterns of work and rest, day and night, sleep and wakeful state, need not be carried with us on space missions. If continuing studies of biological rhythms, especially as applied to man, show that the 24-hour diurnal cycle is the only one natural to man, in which he can work effectively, then a reproduction of earthlike conditions of lighting and temperature cycling would seem called for. However, we already know of both shortening and lengthening of diurnal cycles which have operated fairly successfully for periods of days and weeks. Surely we can encourage investigations of the natural physiological rhythms in the hope of having freer choice if some operational need requires a different regime.

Sleep is still a poorly understood phenomenon, at least physiologically, despite considerable effort in research for some years. It is still possible to make the statement that there are no measurable physiological changes to be found in a person observed before and after a normal sleep. Of course there is a change in body temperature, a slowing of the heart rate, and a few other changes which are primarily matters of muscular quiescence. The important thing is that we cannot detect the difference between fatigue and the refreshed state of a person after having a good night's sleep.

One can also say that we cannot really measure fatigue physiologically. The only successful definitions of fatigue are operational

definitions, and the only measurements that succeed are performance measurements showing decrement. Even these decrements are open to question, since a person sufficiently stimulated or motivated can usually overcome a tendency to make errors, even though he has been performing for an abnormally long time.

Sleep and fatigue may take on some different aspects under the influence of prolonged confinement, isolation, and the effects of null gravity.

Nutrients Required and Psychological Needs

Two kinds of problems come to mind if one actually plans to use body storage in a space mission. First, we should know more clearly what nutrients must be supplied: the essential amino acids, vitamins, etc. to be permitted in the reduced 1400 calorie meals. Second, we must be sure that the reduced caloric intake will not be an annoying or even mildly disabling psychological stress added to the other stresses of the flight.

In the opinion of Kaare Rodahl, reduced diets of the kind described are no problem to men who are excited about what they are doing and kept busy all day long. This opinion is based upon his observation of pioneering and exploring groups in arctic regions. However, one must realize that not all missions will be glamorous and exciting in the same way. For example, a surveillance mission might have certain monotonous aspects. Since eating is a common psychological prop, one would have to find other ways of seeking psychological satisfaction if it were important to include in the mission a low calorie diet. Or alternatively, the satiety value of the food taken should be unusually high.

Effects of Sensory Deprivation and Isolation

The conditions of isolation, confinement and reduced or abnormal sensory inputs are expected to influence the psychological state of the

astronaut. The most likely areas of research are in what is usually called psychophysiology. Specific experimental problems are not defined here. The most important problems will probably be apparent after we have had a few experiences with man in space. Support of existing research programs is important in the meantime.

Using Body Storage

For certain shorter space missions, the ability of the body to utilize its stores of nutrients, water and electrolytes may have very practical value. Dehydration and reduced mineral content probably should not be included in any mission planning, except as a truly emergency mode of operation. On the other hand, storage of nutrients in the form of body fat deposits could well be used as a normal mode of carrying food instead of carrying the food itself.

The starting point of utilization of body fat storage is the potential saving in food energy required for a given mission. Body fat, which is completely utilized without waste, is usually given a value of 4000 kcal per pound. During prolonged low caloric regimes for the clinical control of obesity, one usually calculates weight loss on this basis, adding a fixed amount of 5 to 10 pounds, depending on the size of the person, for water loss during the procedure. In starvation or severe caloric restriction over a short period of time, the figures are a little different. The caloric value of body fat remains the same; however, the loss of water increases. Various experimental determinations have been made. The usual figure is approximately 1 pound of water for 1 pound of body fat lost. This seems to suggest a certain level of dehydration, but one which appears to be quite tolerable.

The usefulness of the idea is seen by examining the following figures. Assume a given astronaut to require 2400 kcal as an energy level in zero g and in the confined space of the cabin. If he is 10 pounds overweight or able to lose 10 pounds of body fat, this gives us 40, 000

extra kcal to work with. Supposing further we offer 1400 kcal in external food, meaning 1000 kcal per day will be taken from body fat stores. This gives our astronaut 40 days of operation on a daily intake level of 1400 kcal and with a weight loss of 10 pounds of fat, and probably an additional 5 to 10 pounds of water which he may or may not be able to recover through ingestion.

Adaptation to High-g Environment

Bioastronautics brings with it a great interest in physiological adaptations to various levels of gravitational force, not only zero g for orbital and interplanetary travel, but multiples of the earth gravitational field to levels such as 3 or 4 g for some of the planets in our solar system.

Some experimental work has been under way for several years with chickens, mice and rats. The work by A. H. Smith at the University of California at Davis shows that chickens can be selected and trained to survive long-term exposures to 3- and 4-g fields, and have a better survival rate than unselected or control birds. The only comparable human work was that of Carl Clark at the Naval Medical Acceleration Laboratory. Clark had considerable difficulty with nausea and visual control from the angular rotation of the centrifuge. This work has not been vigorously followed up. There are interesting physiological implications in the finding that some processes appear to be mass-determined, and some weight-determined.

States of Reduced Metabolism

For prolonged and monotonous periods of interplanetary travel, and possibly for other applications in future space missions, many people think of reduced metabolic states to make the period more bearable, to conserve supplies and reduce the requirement for cycling equipment, and possibly even to reduce the aging process if the voyage is to be extremely extended.

The most frequently referenced condition of this kind, and one in which there is experience already, is hypothermia. Although man is not a natural hibernator, we have much to learn from the natural process of hypothermia which hibernating animals employ. Extensions of our clinical experience of hypothermia used in surgery seem also important. Methods of rewarming, as well as methods of inducing hypothermia, need to be developed fully, since the whole process probably would have to be foolproof and automatic if it were to be practical. At this stage, those people who are working in the field feel strongly that the need is for basic research in the understanding of the hypothermic process. Applications would follow at a much later date.

A number of pharmacologic agents have been used either to reduce or increase mental and physical activity levels. While there is some clinical experience in maintaining patients under sedation for prolonged periods, the effects on perfectly normal subjects so maintained are fruitful areas for future investigation. At the same time it seems reasonable to suggest research interest in the converse state - that of reawakening from reduced states by drugs, or of heightened awareness for certain critical periods through the use of mental stimulants. Drugs to combat the effects of fatigue have been used, but the practice is difficult.

Finally, we come to a never-never land which is carefully avoided by most scientists - the use of Yoga, hypnosis or other trance-like states. The practice of Yoga for religious reasons is an ancient art, and physiologists have been interested in the apparent ability of an individual to control what are usually considered autonomic processes. There have been a few physiological studies of practitioners of Yoga. A condition of profound depression of normal body activities has been observed in such people - very low oxygen consumption, extremely slow heart rate, and insensitivity to normal external stimuli. This is not to suggest that we make Indian mystics of our future astronauts; but it does seem reasonable to encourage greater physiological under-

standing of the processes employed by these people, as a possible kind of methodology to call upon for some future need. The same sort of remarks could be directed toward hypnosis or other techniques for inducing trance-like conditions. Hypnosis is enjoying increasing use by both clinical psychologists and physicians. The phenomenon is real enough, and in the last ten or fifteen years, it has become more and more acceptable to consider making use of this interesting technique. Again, the suggestion is that research be directed toward the understanding of the process or mechanism, with a view to possible future use.

MAN-MACHINE RELIABILITY

The study of the reliability of human performance has been a long-standing and active interest of government and industrial laboratories. The Human Engineering Guide to Equipment Design, to be published next year under the auspices of the three military services, is an example of the productivity of this interest. At the theoretical level, efforts to specify human performance capabilities and limitations have been stimulated by developments in applied mathematics, developments originally intended to apply to problems in the analysis and synthesis of electronic and physical systems. Servo theory, for example, has prompted efforts to study human performance in relation to these concepts. Computer developments have permitted the simulation of human performance in tasks ranging from simple motor responses to problem solving and decision making. Many problems are yet to be solved, and in some instances there is no substitute for a space-based laboratory to carry out a carefully planned program of research. For the present, only the basic laboratory tools available in government and industry can be counted on. Full utilization of this equipment for the study of problems basic to bioastronautics will contribute to the accomplishment of our long-range goals. The following examples illustrate the research needed in the area of human reliability.

The Astronaut as Controller

Can the abilities of the astronaut be utilized in space vehicle control systems to simplify equipment requirements and thus add to system reliability? It is conceivable that a manned space system could play a vital role of inspecting, identifying, and possibly destroying hostile satellite- or missile-launching platforms. Although completely automatic stabilization and control of the inspecting vehicle is possible, it would be desirable to take maximum advantage of the astronaut to simplify the system and thus increase reliability and safety of operation.

To take a particular example, suppose that two vehicles are in the same circular orbit, and that one vehicle desires to catch up with the other. The astronaut can apply an impulse of thrust to increase speed, but then he must also provide a continuous downward force to balance the increase in centrifugal force. When he uses reverse thrust to slow vehicle speed, he must simultaneously reduce the force normal to the trajectory at the proper rate. This maneuver is wasteful of rocket fuel, and there are more economical ways to catch up. The better way is to use downward and upward impulses to move into an orbit of smaller radius, and then move out to the original orbit. Therefore, we ask, how is a pilot going to learn to maneuver a vehicle under conditions where forces in the up-down direction are used to control speed and, conversely, in the fore-aft direction, to control altitude? Moreover, the control situation is complicated by the fact that trajectory characteristics are different for maneuvers in the orbital plane and maneuvers perpendicular to the orbital plane. To make the observations and calculations necessary for determining the optimum path and use of thrust is a complex task even for an automatic control system. Can we find, however, simple ways for the pilot to make the required observations and exert control so as to achieve reasonably efficient trajectories without dependence on elaborate computers and sophisticated displays? To what extent can we develop and take advantage of human skills in this type of maneuver? Can the pilot learn to fly by visual observation alone? What sort of display and

control systems need development so as to achieve reliability through inherent simplicity? An important question is, therefore, "What are the trade-offs between crew utilization and the need for automatic navigation, guidance and control equipment?"

Unique Coupling Techniques

Traditionally, man has been linked to the machines he operates by means of displays and controls. Displays provide input data for the human senses, and the muscles in turn provide the force to actuate machine controls. Are there more direct ways of coupling the man to his equipment? Is it possible to bypass the display - human senses link by inserting signals more directly into the nervous system? Is it possible to obtain signals from the human operator for machine control before his muscles are involved? These are intriguing questions, highly speculative as to outcome, but some work is now under way to establish the possibility of direct coupling. It is much too early to predict the outcome of these investigations, but the goal is not unreasonable.

It has been demonstrated by Uttal of International Business Machine's Research Center, Yorktown Heights, N. Y., that a person can voluntarily control the electrical activity of the brain if he is permitted to observe the waves displayed on an oscilloscope.

Theoretically, it is possible to train a person to communicate voluntarily with a machine through the exercise of such mental control. While this goal seems distant at present, brain-machine communication of binary responses is within the bounds of current technology. Further research along these lines should have important implications from the treatment of mental illness to the more rapid implementation of executive decision, as well as for space flight.

Acceleration and Vision

Acceleration (g) continues to play an important role in the manned space flight program. Although the contour couch and the supine body position ameliorate gross cardiovascular disturbances, certain phenomena remain that have not as yet been adequately explained. For instance, the Mercury astronauts have experienced alterations in vision during acceleration that cannot be accounted for in terms of hemodynamic changes. The mechanical effects of acceleration on the visual system have not been fully explored.

Nutrition and Behavior

Earlier, we mentioned the use of pharmacological agents to achieve a biologically optimum environment. There are other avenues to the achievement of increased human reliability. Among those variables which affect the over-all efficiency of the astronaut, there are few more important than nutrition. Two decades of research, beginning about 1930, produced a wealth of information on the relation between diet and performance. During this period, the role of vitamin A in night blindness was firmly established; the view that diets high in carbohydrates and low in protein were desirable for preflight and inflight feeding of air crews was experimentally verified; and, the combined effects of alcohol, tobacco and altitude on human efficiency were fully explored. Today, our need for information about diets and human efficiency are different. Samuel Lepkovsky, prominent nutritionist at the University of California, has observed, "We are witnessing the end of an era in nutrition - an era of essential nutrients. A new era in nutrition is in the making, and its dim outlines are beginning to emerge." The era must surely emphasize studies in which an attempt will be made to correlate behavior with diet and the nutritional status of the individual. Luman Ney, senior biochemist at Stanford Research Institute, has said, '...the demands that we contemplate improving upon ourselves in order to make manned excursions into space require that we know a great deal more about both minimal

"and optimum values in individual nutrition. The space age may provide the impetus for greatly accelerated advance in this direction, because of the needs for obtaining optimum human performance and, at the same time, minimizing the payload of food."

Automated Instruction

The reliability of man's performance can generally be increased by improved and expanded instruction in the tasks he is to perform. Present instruction aids, such as flight simulators and teaching machines, require detailed pre-programming, and hence complete prior knowledge of the task to be performed and the possible errors which can be made in this task. Such prior knowledge may not be available in new systems, such as exploratory space vehicles.

An alternative to a pre-programmed teaching simulator could be a simulator controlled by an adaptive heuristic computer program. In the general problem solving task to which heuristic programming has been applied, there is a set of rules which specify the known characteristics of the system concerned, a present state of some variable, a desired future state or goal, and a set of operations which can transform the variable from one state into another. A set of heuristics is used to select the sequence of operations which will, if successful, lead to the goal.

The astronaut training situation can be fitted into this framework. The present state of the astronaut training is to be transformed into some desired future state. The computer can provide certain problems to the astronaut, such as normal mission specifications and emergency conditions. By analyzing the astronaut's response to each problem, a suitable following problem can be selected, to correct his errors or further advance his skills.

COMMENT

We said earlier that there are two criteria for setting our future research goals. On the basis of the internally funded projects described in the questionnaire-inventory, and of what is already known about government sponsored projects, the first criterion is to accomplish what is already under way, and this, in a general sense, is possible by use of today's technology. Effectiveness, in this respect, is directly related to placement of effort. In certain areas, incentive to the achievement of the necessary end is lacking, and in others there is duplication of effort. The reasons may vary, but it can be assumed that financial profit, low-cost projects, and lack of awareness of needed research all play important roles in this situation.

The second criterion is that of innovation, and it has greatest application to a long range program. We have discussed a selection of possible fruitful areas of investigation which could be useful to various kinds of organizations in directing their energies toward a movement beyond current technology. This selection was compiled on the basis of what seemed to be lack, or gaps, as shown in the questionnaire response when related to known areas of needed research and development. Insofar as these investigations are missing from the current development of man's potential productivity in space, they have a purpose and use.

Large sums of money are now being invested in bioastronautics, and these will be multiplied in the next few years. Research and development must proceed along a charted course, else the dissipation of our resources will deprive us of all hope of national support. This support is necessary if we are to fulfill our moral and political obligation of preeminence in space.

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